MEBT status

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for the PXIE warm front end group

PIP-II technical meeting

January 20, 2015

Outline

- Overview
- Status of elements
- Configurations for RFQ beam commissioning
- Plans

Goals and status

- Main final goals stay the same:
  - Demonstrate creating an arbitrary bunch pattern from initially CW 5-10 mA, 2.1 MeV H- beam
  - Compatibility with SRF downstream
  - Provide all modes that may be required for PIP-II

- The specifications and scheme did not change for ~3 years
- All major components are under development

- Parts of MEBT will be used to characterize the beam from RFQ
  - A set of configurations is under design

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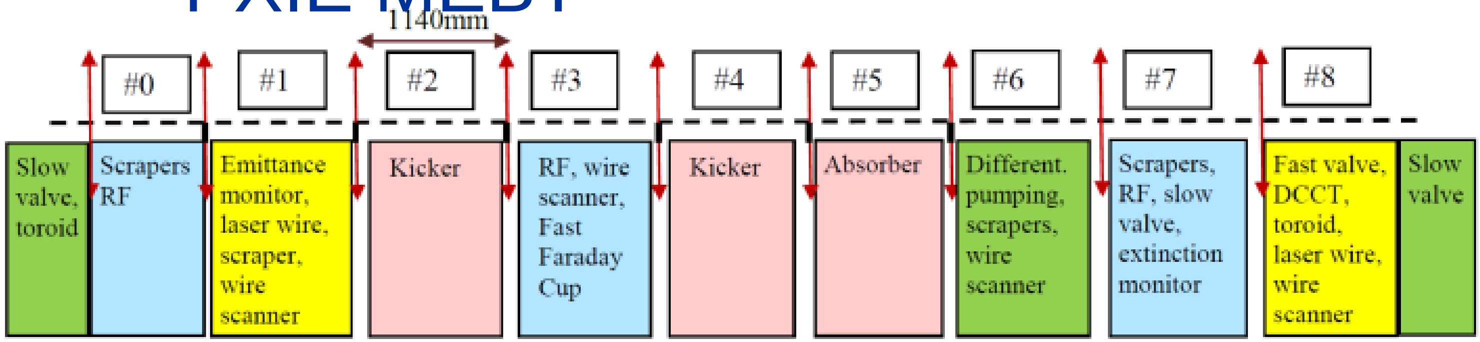
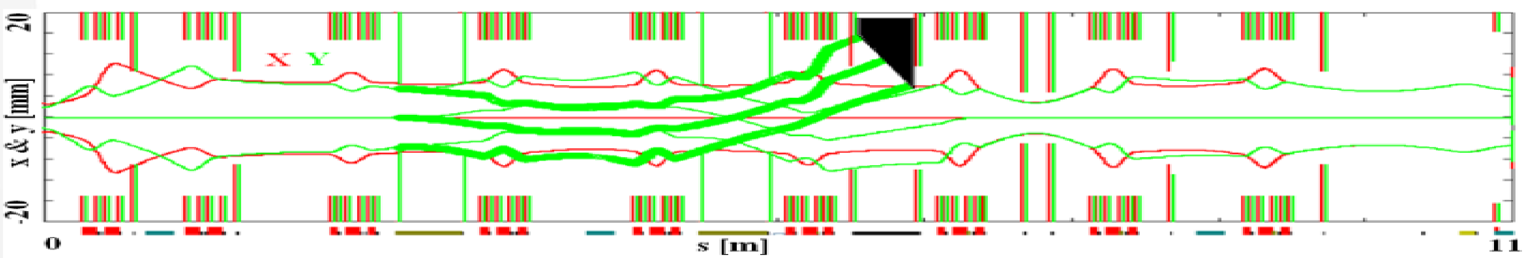
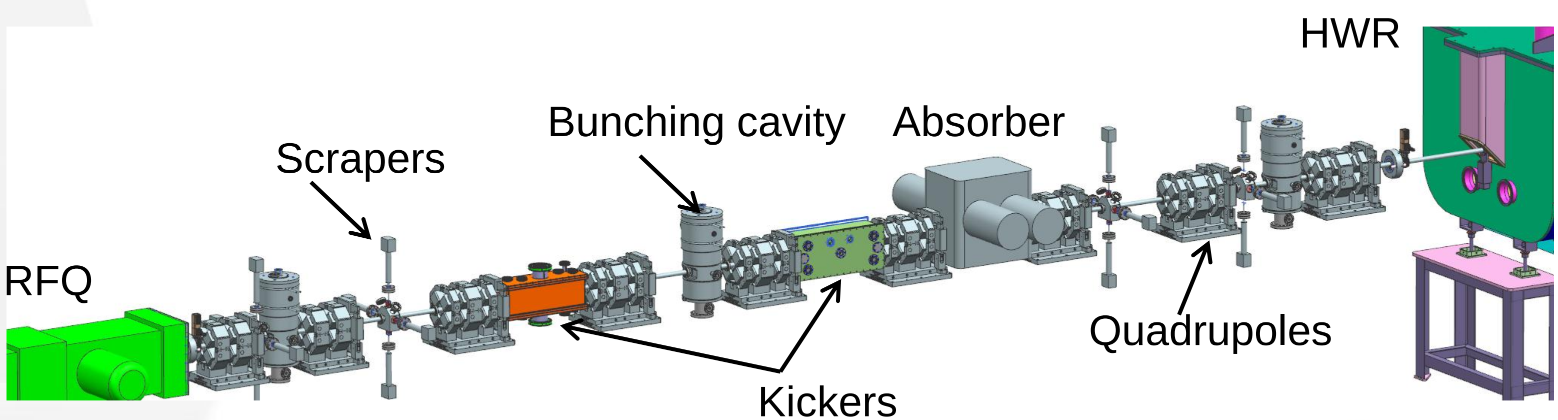
PXIE MEBT



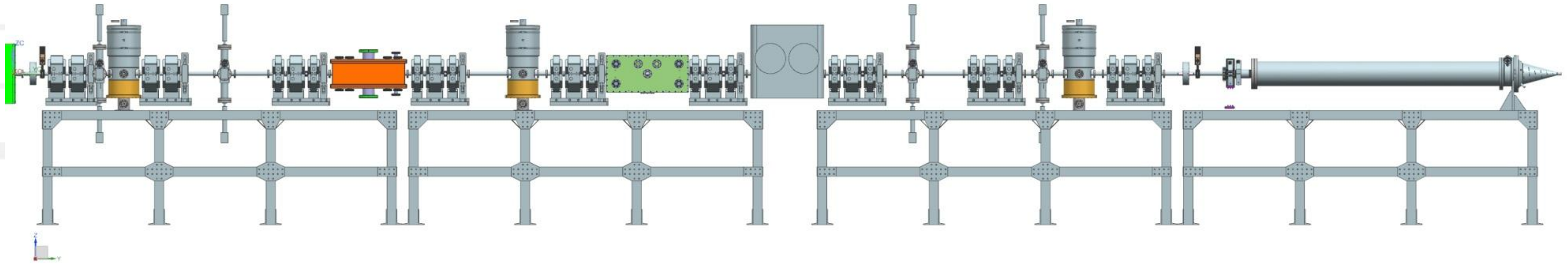




Fermilab

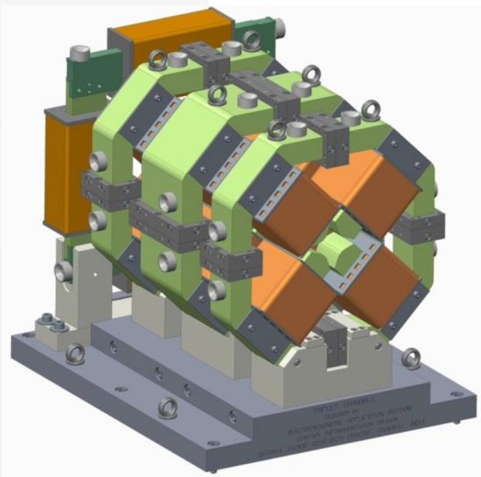
MEBT elements

- Magnets
  - Quadrupoles and dipole correctors
- Kickers
- Absorber
- Bunching cavities
- Scrapers
- Diagnostics
- I will not cover LLRF and controls
- Mechanical design of the entire MEBT is expected to start in April 2015, when the LEBT is finished



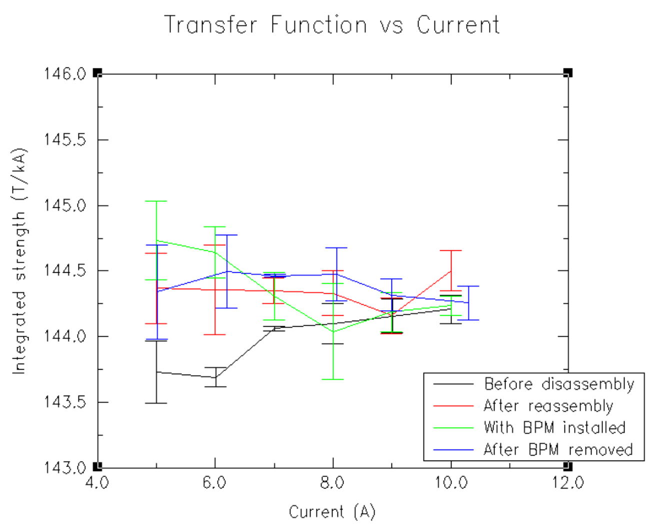
MEBT magnets

- MEBT needs 2 doublet and 7 triplet assemblies
  - Each assembly includes a pair of dipole correctors
  - Design incorporates a BPM inside triplets/doublets



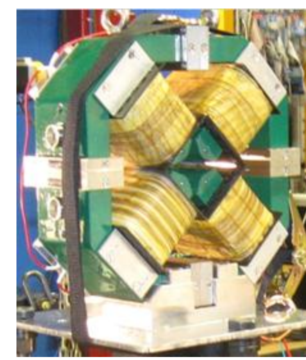
Triplet assembly. Image courtesy of BARC, India.

- Quadrupoles and dipole correctors have been developed and will be built at BARC, India
  - Prototype magnets have been built and measured both at BARC and Fermilab
    - Quality is within specifications



Quad field integral vs current. From M. Tartaglia, PX DB 1323

BARC's F-Quadrupole prototype

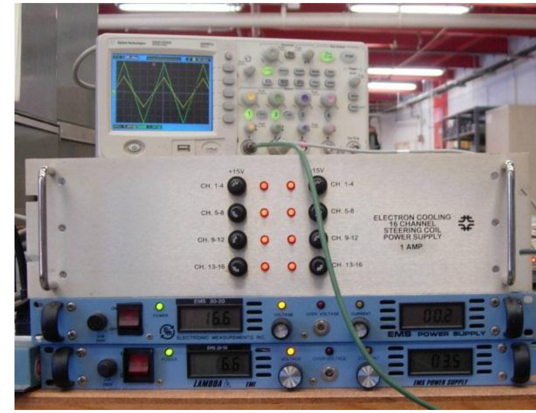


MEBT magnets - status

- Prototypes of the doublet and triplet are complete by BARC
  - Will be delivered to Fermilab after magnetic measurements
  - Will be re-measured at TD
- Quads will be re-arranged to make two doublets with dipole corrector sets
  - Prototypes of F-quad and corrector set that are already at Fermilab will be used
  - Covers a “short MEBT” configuration (see later) for RFQ beam characterization
- All dipole corrector sets are expected to be ready for shipment in Summer 2015
- The schedule for production of all quadrupoles is being discussed

MEBT magnets – power supplies

- MEBT magnets will be powered by power supplies from former Ecool
- Quadrupole PSs are LAMBDA (10A, 20V)
  - Have all (18+2 spares) on hands; need controls
- Dipole corrector PSs (4A, 10V) will be based on Ecool corrector PSs
  - Made in-house, G. Saewert. Test of combining four 1Amp PSs into one 4Amp was successful
  - Re-packaging is under way (R. Brooker)
- Power supplies have been tested with the magnet prototypes delivered by BARC
  - K. Carlson, G. Saewert
  - Current stabilization is better than specified
- All power supplies are planned to be ready by summer 2015



Correctors power supply testing.

Quadrupoles power supplies in a rack. K. Carlson.

Photos: B. Hanna

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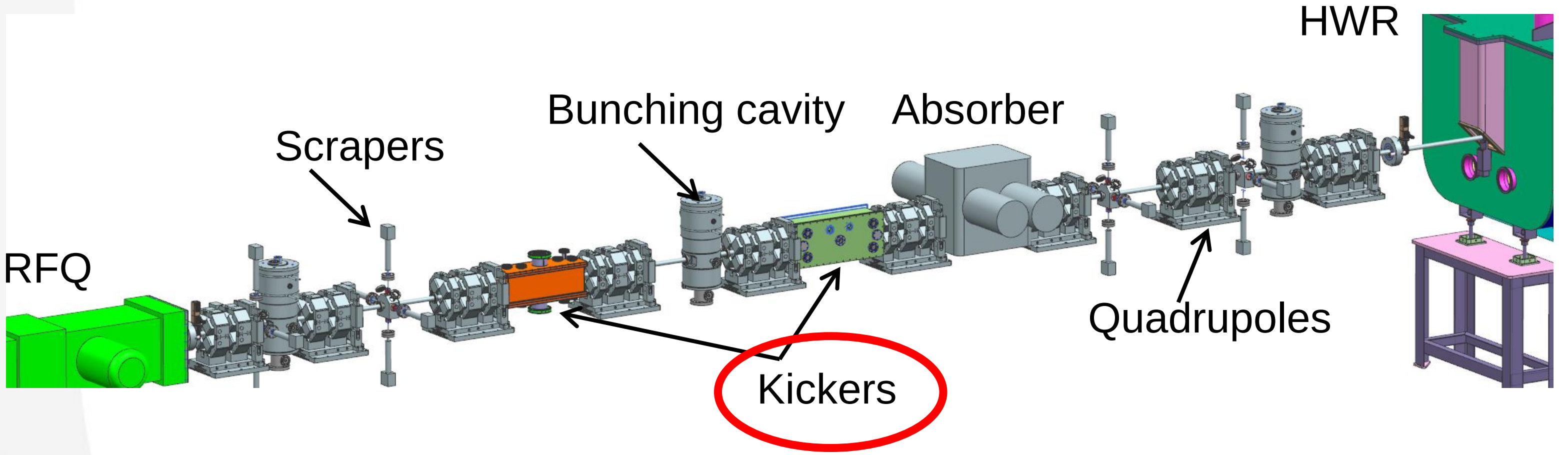
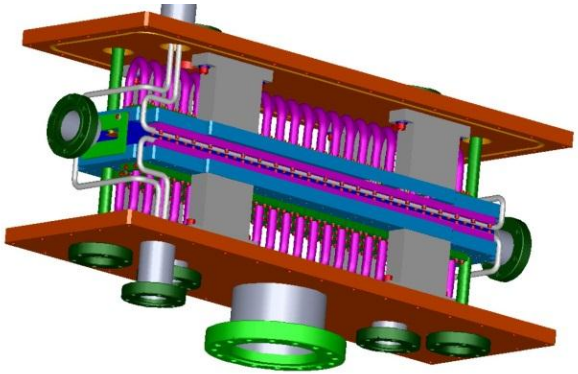
Kickers



- Developing in parallel two versions, “50 Ohm” and “200 Ohm”
    - The technology choice will be made after tests with beam

50 Ohm kicker - concept

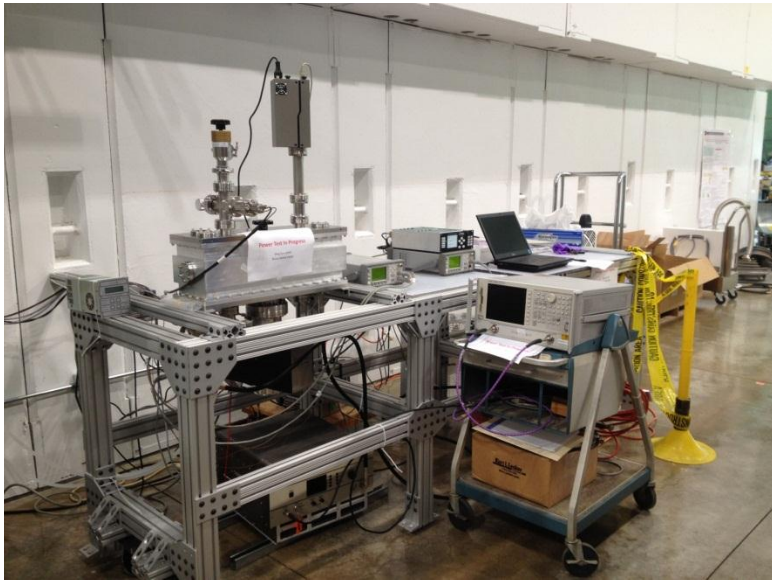
- Kicker
  - 24 electrodes per plate connected in vacuum by 50 Ohm cables
- Driver
  - Commercially available linear amplifier
    - Do not plan to purchase yet
    - The concept has been tested with a similar lower-power amplifier



D. Sun, A. Chen

50 Ohm kicker - status

- One half of the kicker prototype was assembled and tested
  - Excellent delay time
    - 21.98 ns vs specified 21.97±0.1 ns
  - Power test in vacuum with 250 MHz amplifier
    - By the power left in the structure, 570 W applied to the kicker at 250 MHz is equivalent to specified 625 W at expected wave form
    - Stayed 4 hours at maximum power. Vacuum $6 \cdot 10^{-7}$ Torr. Temperature rise of an electrode (measured with IR camera) was 14C. RGA scans did not indicate excessive organic components.

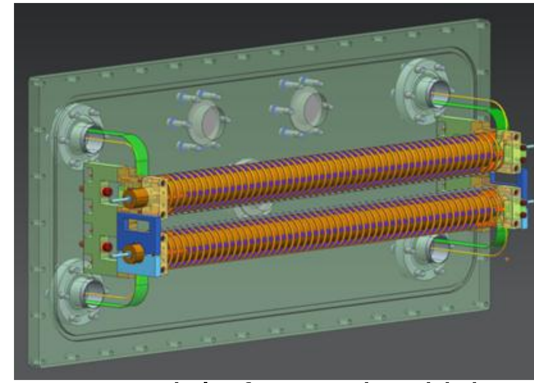


50 Ohm kicker power test setup. D. Sun, A. Chen, D. Petersen, D. Franck

- The second half of the kicker is being assembled
  - The complete kicker prototype is expected to be power-tested with 162.5 MHz amplifier in spring 2015

200 Ohm kicker - structure

- Helix as a travelling-wave structure
- One helix was manufactured and measured
  - The delay time is off by 5%, so the final helix winding needs to be adjusted for the beam tests
  - In addition, ceramics permittivity was measured (S. Kazakov)
- One- helix assembly is being assembled for power tests in vacuum
  - First, test the design for handling of anticipated beam losses
  - Then, test with a 35 MHz, HV RF driver source for measuring the effects of RF losses



3D model of 200 Ohm kicker.
G.Saewert, A.Chen, M. Jones

One helix is being prepared for power tests.
G.Saewert, A.Chen, D. Franck

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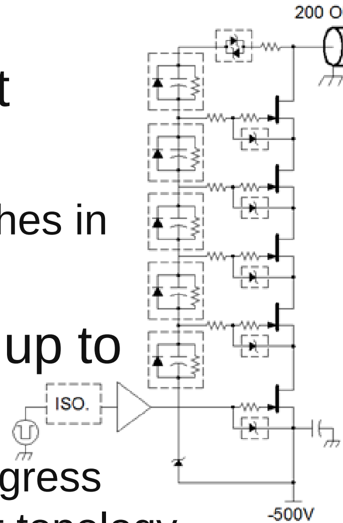
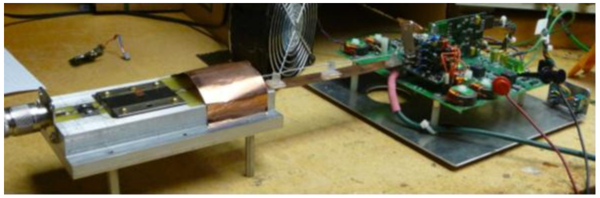
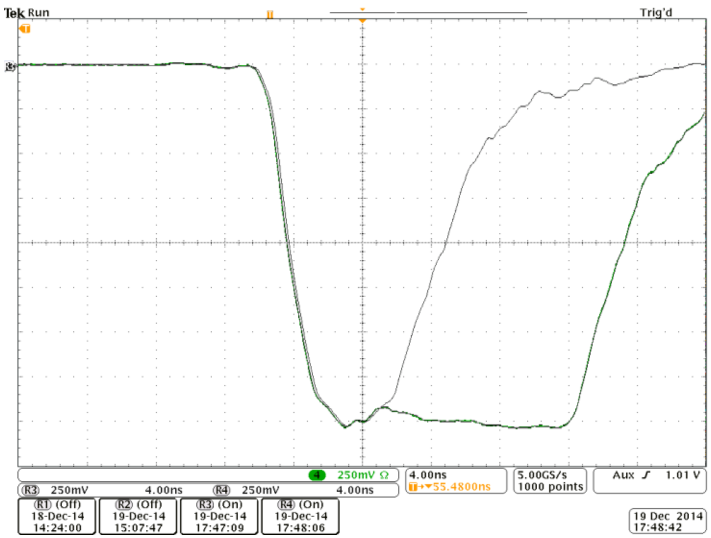
200 Ohm kicker - driver

- Driver is being developed at Fermilab (G.Saewert)
  - Broadband, DC coupled switches in push-pull configuration
- Push-pull driver was tested up to 200V
  - It was determined that the progress toward 500V requires different topology, which now is being pursued within LDRD
- Single switch was tested up to 500V
  - Being prepared for RF power testing the helix prototype

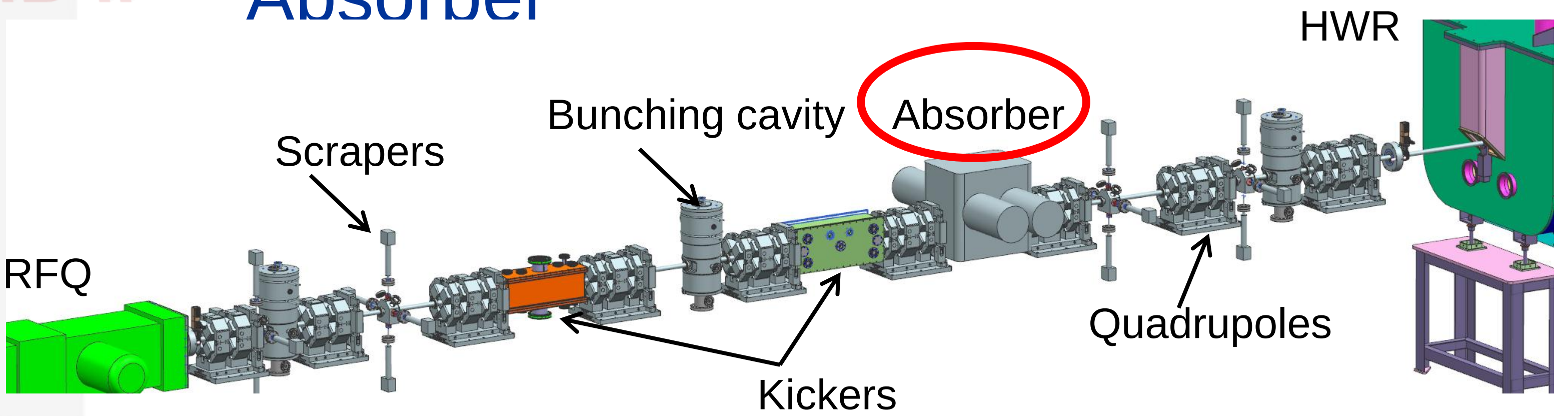






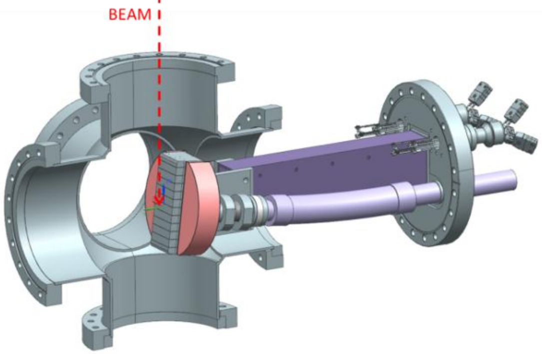
Output of 500V low-side switch. 4 ns and 20 ns wide pulses are superimposed. Leading edge is 2.0ns, trailing edge is 9 ns (5%-95%). 1 MHz CW, 200 Ohm load. Resistive load/monitor is bandwidth limited resulting in the leading edge appearing to be 3.2 ns.

Absorber

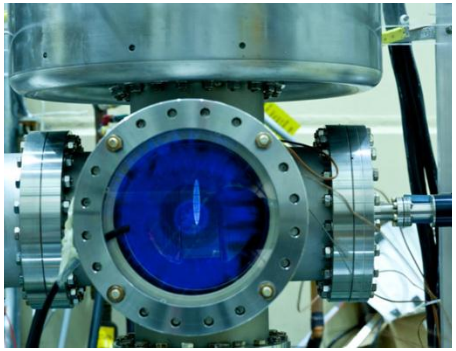


- 21 kW CW, 2mm 1σ beam; absorber of 50 cm length, 29 mrad grazing angle, 17 W/mm^2 of surface power density
- Features: Molybdenum alloy TZM, transverse slits to alleviate stress, shadowing steps to protect the slits
- Two ¼-size prototypes were successfully built and tested with an e-beam (28 keV, 0.19A) at comparable power density
  - Reasonable agreement with ANSYS simulations
  - Plan to test Prototype-II in full-length MEBT before proceeding to final absorber

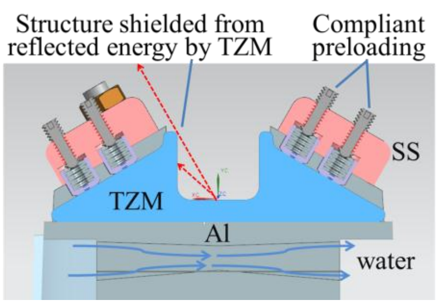
Prototypes



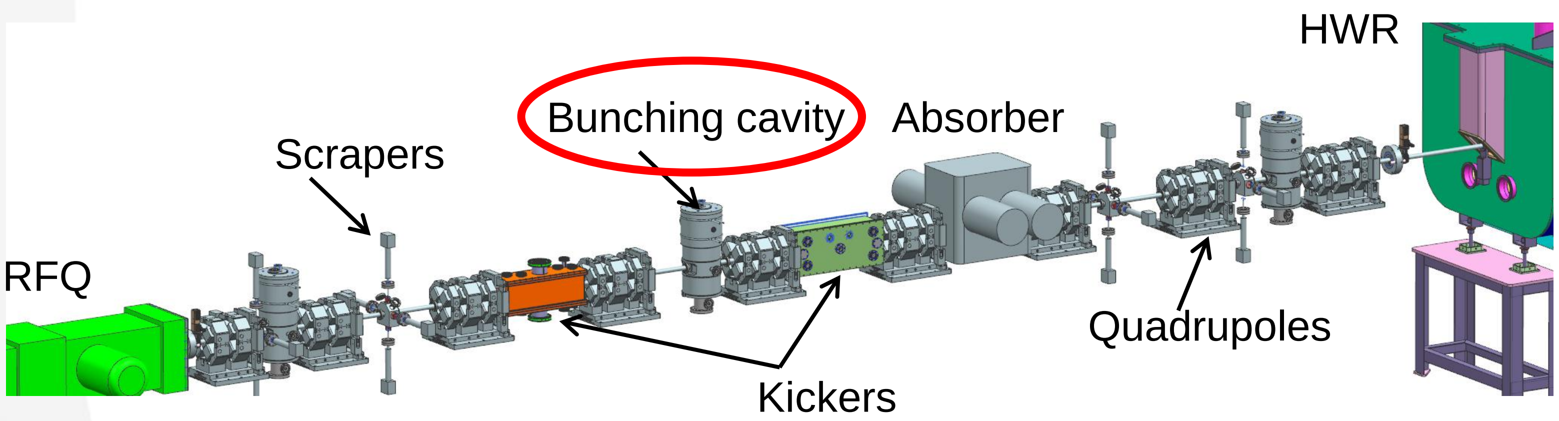
- Prototype-I: monolythic design
  - Complicated manufacturing process; a possibility of a crack to water
  - Tested surface power density up to 17 W/mm^2 with surface temperature up to 1300 K
- Prototype-II: separate TZM plates pressed against a water-cooled aluminum plate
  - Sacrificed thermal properties (~25% higher temperature rise) for simplicity and reliability
  - Also, better management of reflected particles
  - Was tested with power density well above the expected at PXIE, to ~30 W/mm^2 with surface temperature up to ~1600K
  - Survived >10^4 thermocycles in 8 days



C. Baffes



Bunching cavities



- 162.5 MHz, 100 kV max
  - Expected power in copper ~1 kW
  - Need 3 cavities

Bunching cavities - status

- A prototype cavity has been brazed and is at Fermilab
  - Resonant frequency is good (T. Khabiboulline)
  - A big vacuum leak was found (D. Plant)
  - The plan is to seal the leak and proceed with high-power RF tests
  - 3 production cavities will be procured following the tests
  - The prototype cavity will be used in “short MEBT” configuration
- Five 3-kW amplifiers have been ordered (R. Pasquinelli) and expected to be delivered in Feb 2015

The cavity prepared for the leak test. Photo courtesy of L. Ristori, lead production engineer.

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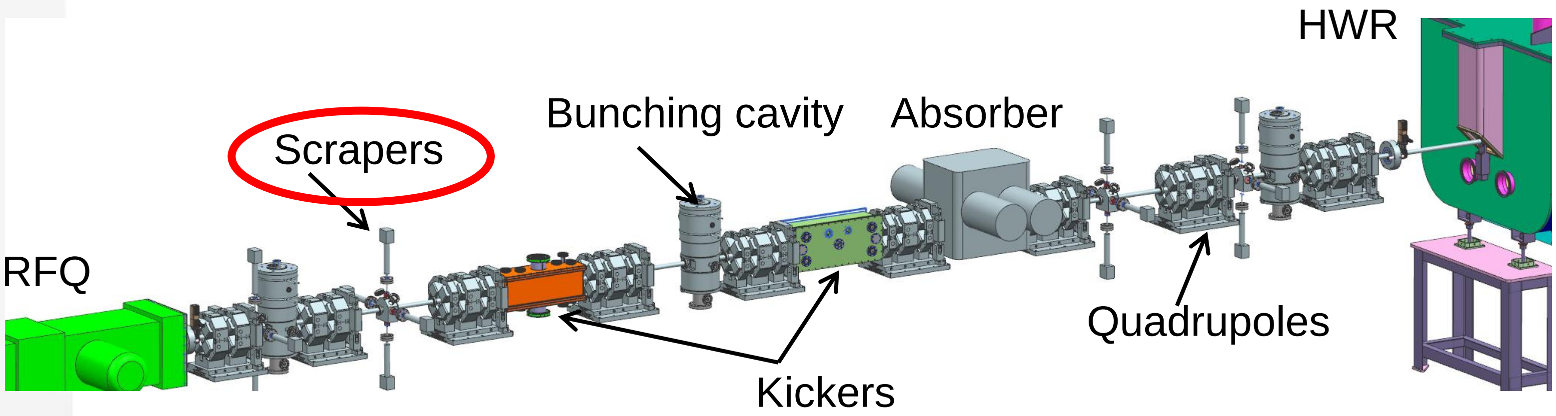
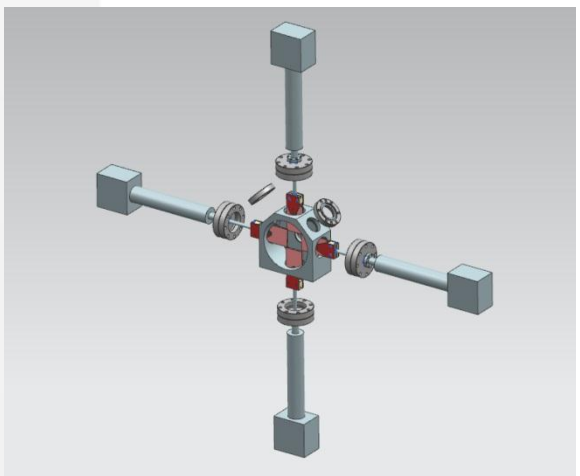
Scrapers



- 4 assemblies, 4 scraper jaws in each
  - To be used for beam scraping, machine protection, and beam size estimations
  - Max 50W per jaw. A prototype was tested with an electron beam up to 150W.
  - Radiation – cooled, electrically isolated, independently movable TZM plates
  - Linear drives from ECool

Scrapers - status

- The first set is being assembled
  - May test it at LEBT in spring 2015
  - Will manufacture 2 more in FY15



Model of the scraper set.
C.Baffes

Assembling the scrapers. K. Kendziora

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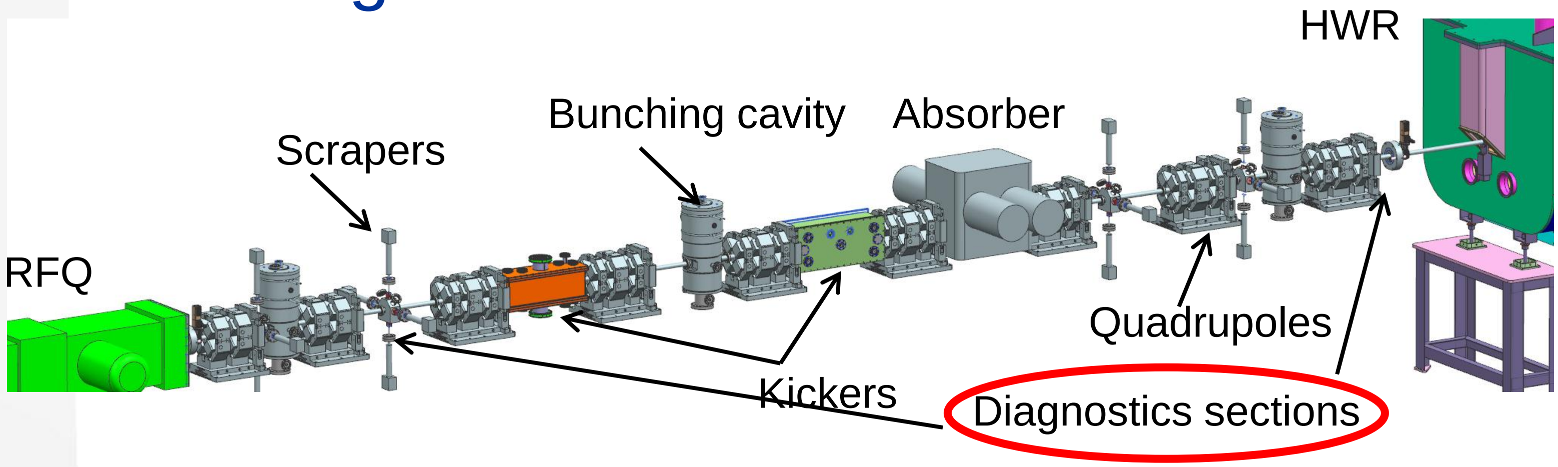
Diagnostics



- Will be mainly in two "diagnostics" sections of the final MEBT
  - The final set may include: 9 BPMs, 2 toroids, DCCT, 4 x 4 scrapers, emittance scanner, 2 wire scanners, Fast Faraday Cup, 2 laser wires, extinction monitor
- Because of resource limitations, the diagnostics will be installed sequentially over years
  - FY15: 2 toroids, 2 BPMs, 1x4 scrapers, Fast Faraday Cup, ToF. Should be enough for initial RFQ characterization

Diagnostics - status

V. Scarpine, M. Alvarez

- BPMs
  - One BPM is complete and measured
  - One more BPM is in production; have buttons for 2 more
  - Electronics for 2 BPMs should be ready by summer 2015
  - Buttons for all MEBT BPMs have been ordered
- Time-of-Flight monitor (“movable BPM”) – being designed
  - To measure the beam energy by recording the phase as a function of the longitudinal BPM position, following an idea from SNS
- Fast Faraday Cup – being designed
  - Small portion of the beam is cut by a pinhole and collected to a strip line
  - Modifications to SNS design to improve robustness

2 toroids – on hands

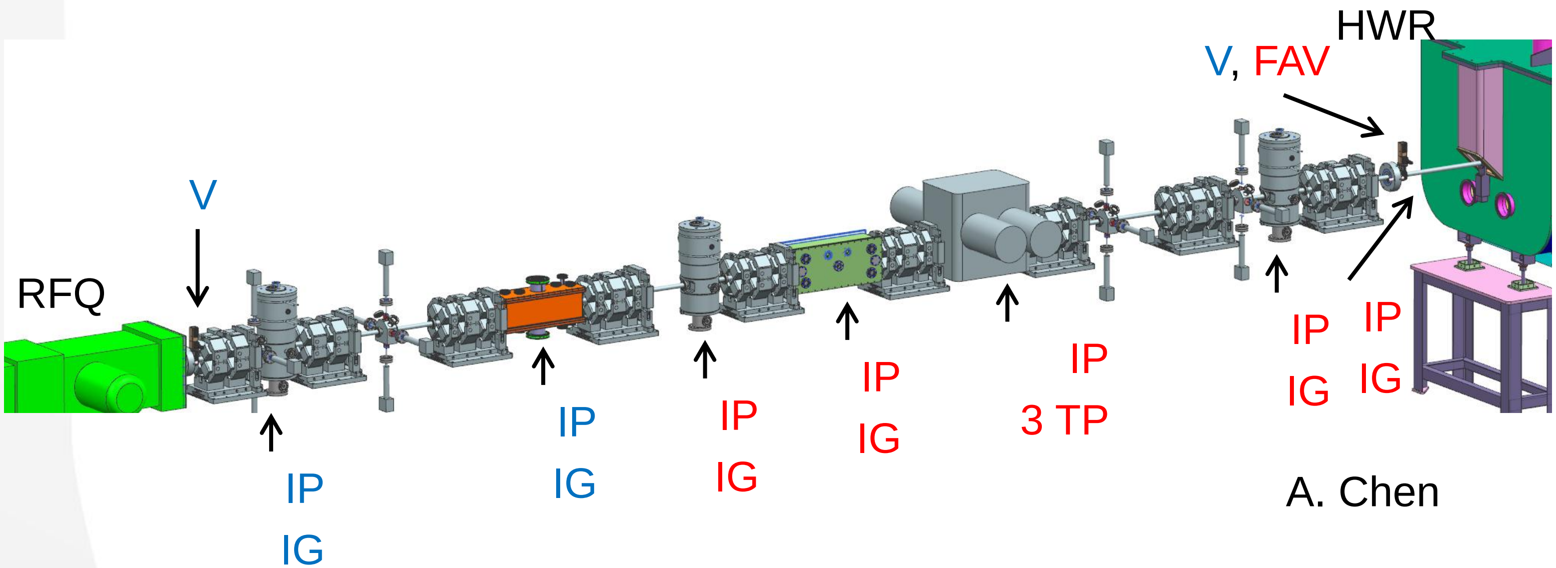
Ring pickup – being procured
  - To estimate average beam current from RFQ for MPS purpose

Diagnostics – preparation for FY16 and beyond

- Emittance scanner
  - Will try to use slits in scraper jaws as double-slit scanner
  - Initial commissioning with the LEBT scanner (see later)
  - We also will measure the emittance by quadrupole scans
- If the scraper set assembly is found convenient, it may be used as a base for wire scanners
- Should have buttons for all BPM by summer 2015
  - To prepare all BPMs and triplet vacuum chambers by arrival of MEBT magnets
- Development of the laser wire has started
  - V. Scarpine, J. Ruan
  - Expensive and long – term work
  - General R&D in this direction within LDRD may help making the system less costly

PIP-II

Vacuum



IP – ion pump, TP- turbo pump, IG – ion gauge, V- pneumatic valve, FAV- fast acting valve. Blue – on hands, Red – need to purchase.

- Elements of vacuum system have been identified
  - Purchased elements needed in CY15

MEBT in 2015

- In 2015, parts of MEBT will be used for the RFQ beam commissioning and characterization
  - Expected to be in steps
- So far, all elements are on the path to work with a short-pulse beam in the end of FY15 (next slides)
- Plan to have high-power beam tests toward the end of CY15

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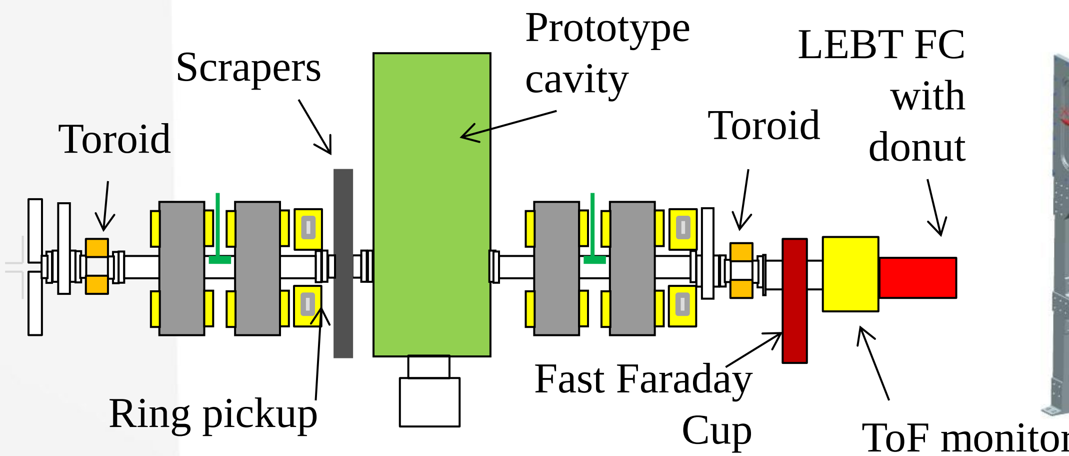
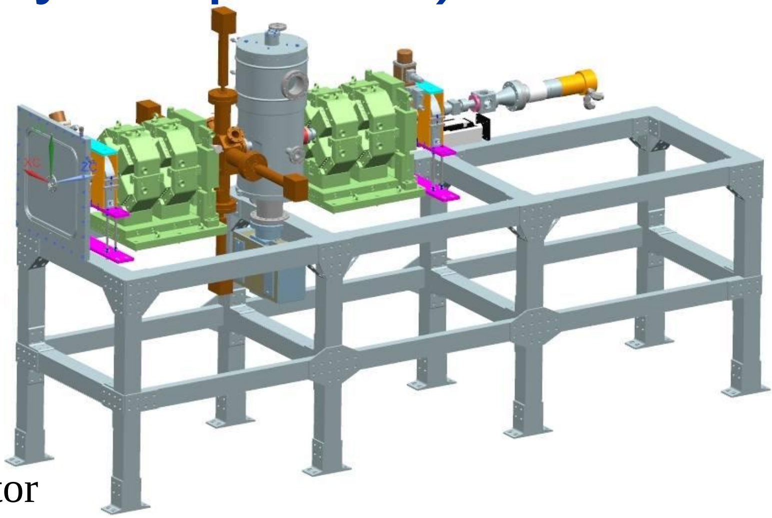
"Short MEBT 1_1" (July- Sep 2015)

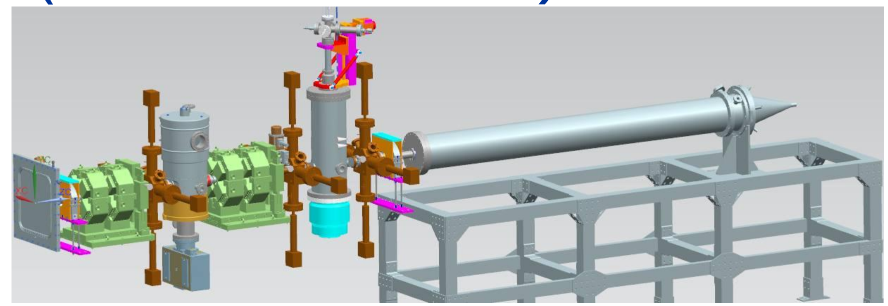




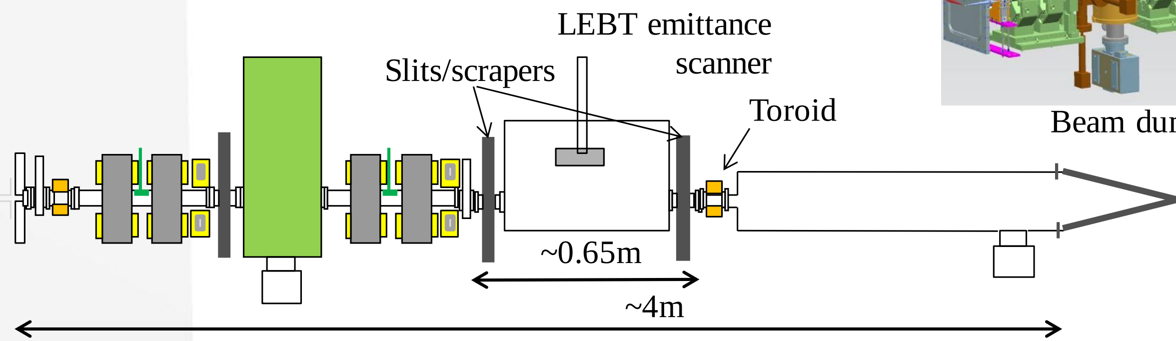
- Plan to start RFQ beam commissioning including MEBT section #0 fully assembled with prototype magnets and cavity
  - Pulsed mode only (<1 ms)
  - Protection from CW by MPS through a ring pickup signal
  - Commissioning of toroids, BPMs, scrapers, FFC, ToF, magnets
  - Measurement of beam energy, RFQ transmission, bunch length
  - If ready with RFQ frequency stabilization, commission the buncher

“Short MEBT 1_2” (Oct- Nov 2015)

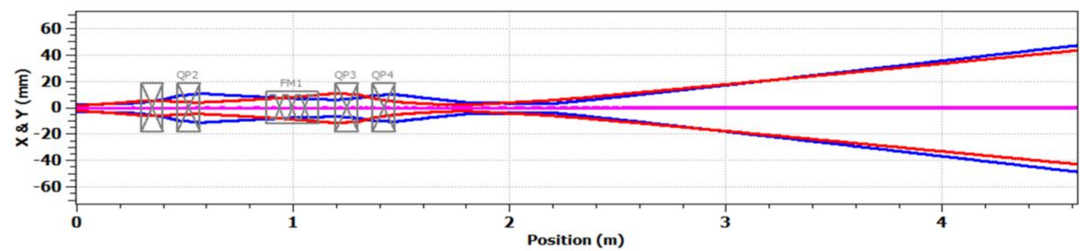
PIP-II



3D model of MEBT 1_2.
C. Baffes, S. Oplt.



- Measurements of beam emittance, Twiss functions
  - Start with the LEBT emittance scanner, compare with measurements by slits/scrapers

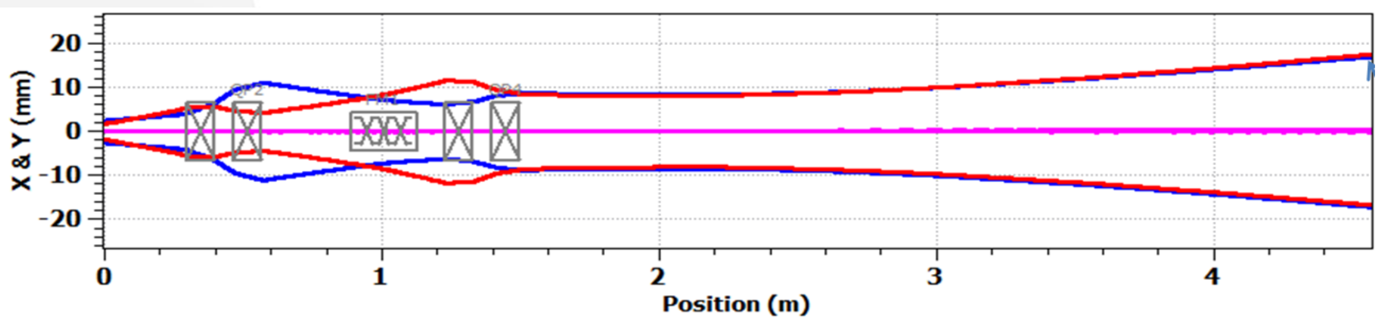


3σ beam envelope 3D simulation for high-power tests. A. Saini. 5mA.

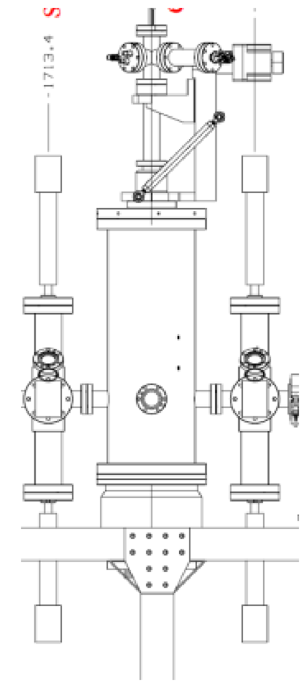
- First high – power tests
  - SNS beam dump (from HINS)
  - 16 kW power test will be done with the “instrumentation” section removed

LEBT scanner in MEBT

- Very attractive to try using the LEBT scanner for initial RFQ beam commissioning
  - The Allison scanner is much faster than double-slit
  - Commissioned at LEBT; could be used for cross-calibration of slits
  - H- energy is by 70 times higher => the kick angle is 70 times lower => ±180 mrad in LEBT corresponds to only ±2.5 mrad in MEBT
  - Conclusion: Can be used if emittance is not too large with a specially prepared envelope

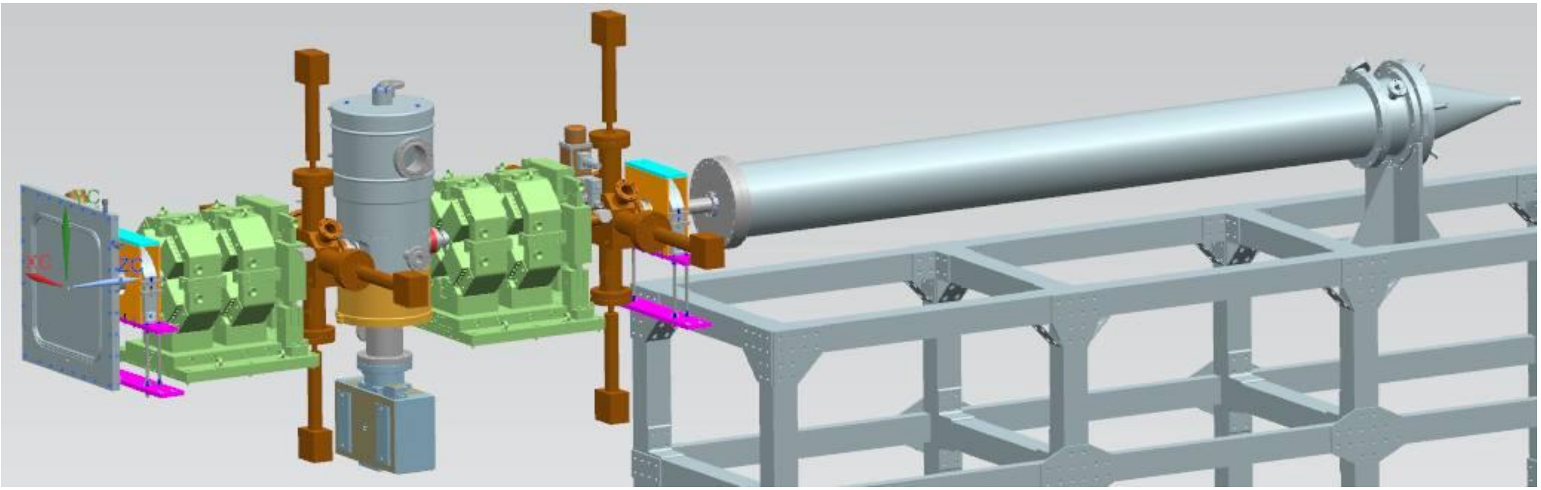


3σ beam envelope 3D simulation for LEBT scanner use in MEBT. A. Saini. 5mA, transverse emittance 0.21 μm (rms, n). 3 σ beam angle in the proposed location of the scanner is 3.5 mrad.



Placement the LEBT scanner between two scraper sets. C.Baffes, S.Oplt.

“Short MEBT 1_3” (Nov 2015)

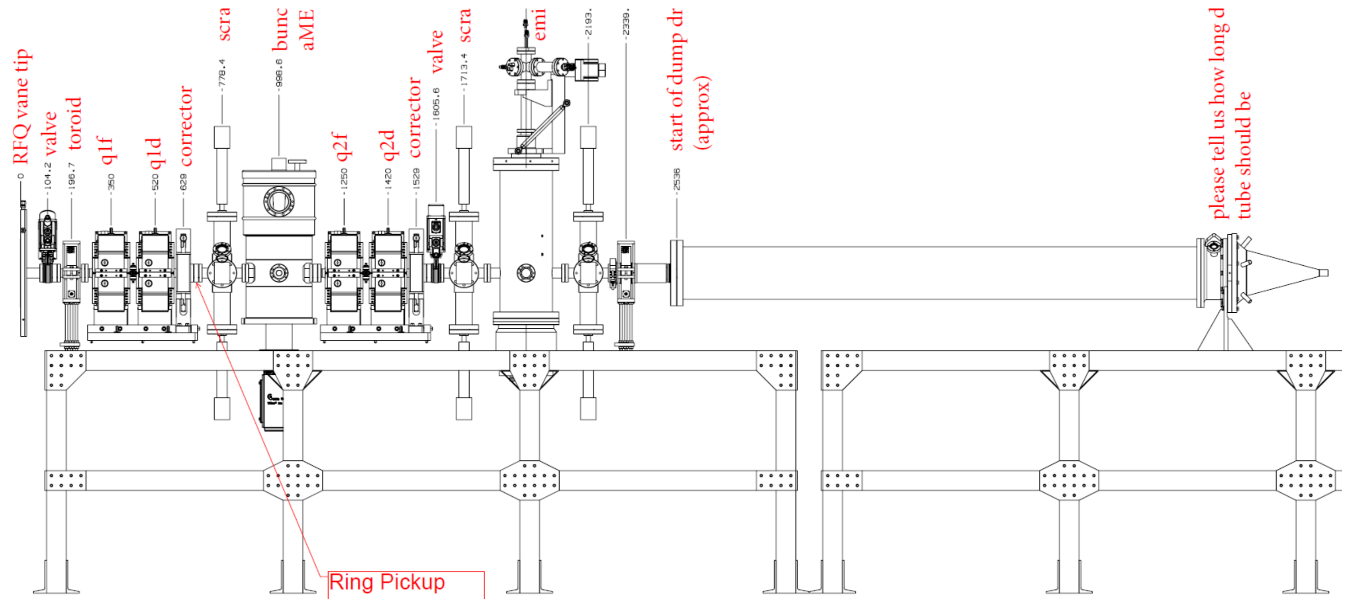


3D model of MEBT 1_3.
C. Baffes, S. Oplt.

- 16 kW power test may require a removal of the “diagnostics section”
  - To provide larger beam at the dump
  - The same components

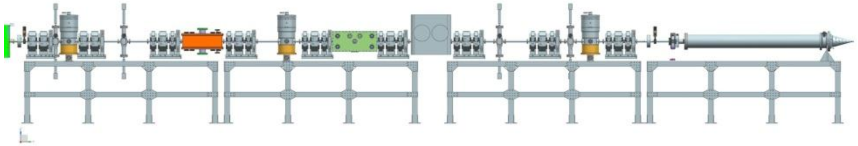
“Short MEBT” preparation

- 3D models of first configurations are prepared
- All components for “short MEBT 1_1” should be ready by July 2015 for RFQ beam commissioning



Model of short MEBT 1_1
C.Baffes, S.Oplt.

PIP-II MEBT plan (technically driven, with no contingency)



- Aug 2015 – pulsed beam from RFQ
- Nov 2015 – CW beam
- Dec 2015 – Feb 2016 – installation of full – length MEBT
  - With prototype kickers (50 Ohm and 200 Ohm) and 5 kW prototype absorber
  - Final bunching cavities, final magnets, SNS beam dump at the end
  - Incomplete diagnostics (e.g. no wire monitors, extinction monitor, laser wire etc.)
- Mar –Jul 2016- initial MEBT commissioning
  - The main goal is to pass the beam to the chopper to test its elements
  - Make decision on the kicker technology; start the final chopper design
- Aug- Nov 2016 – all cryo work and SSR1 installation
- Dec 2016- Aug 2017 – MEBT characterization
  - In parallel with SSR1 commissioning
- Sep – Dec 2017 – final MEBT installation (concurrent with HWR’s)
- FY18 – demonstration of bunch-by-bunch separation